

PCT

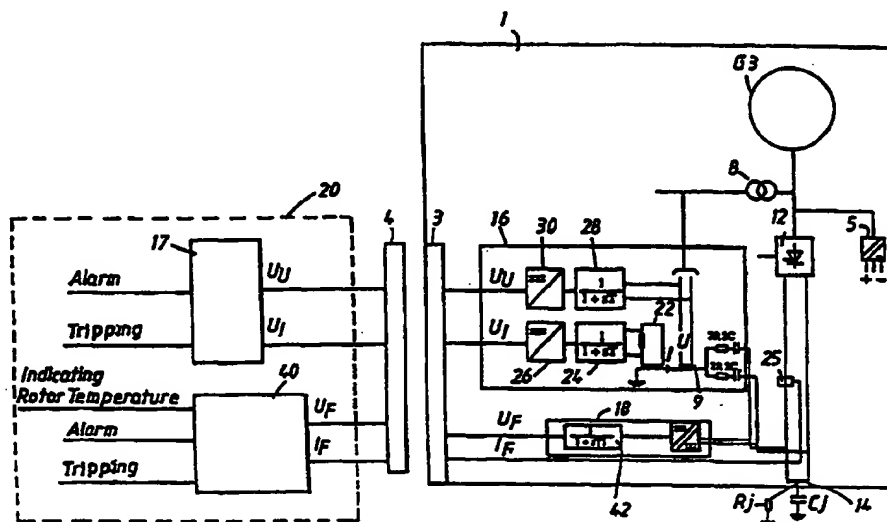
WORLD INTELLECTUAL PROPERTY ORGANIZATION  
International Bureau



INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification <sup>6</sup> : H02K 3/40, G01R 31/06		A1	(11) International Publication Number: <b>WO 99/19963</b>
			(43) International Publication Date: 22 April 1999 (22.04.99)
(21) International Application Number: PCT/SE98/01740		(81) Designated States: AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CU, CZ, CZ (Utility model), DE, DE (Utility model), DK, DK (Utility model), EE, ES, FI, FI (Utility model), GB, GE, GH, GM, HR, HU, ID, IL, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SK (Utility model), SL, TJ, TM, TR, TT, UA, UG, US, UZ, VN, YU, ZW, ARIPO patent (GH, GM, KE, LS, MW, SD, SZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).	
(22) International Filing Date: 29 September 1998 (29.09.98)			
(30) Priority Data: 9703554-7 30 September 1997 (30.09.97) SE			
(71) Applicant (for all designated States except US): ASEA BROWN BOVERI AB [SE/SE]; S-721 83 Västerås (SE).			
(72) Inventors; and			
(75) Inventors/Applicants (for US only): SÖRENSEN, Erlend [SE/SE]; Gudruns väg 32, S-723 55 Västerås (SE). LEIJON, Mats [SE/SE]; Hyvrlargatan 5, S-723 35 Västerås (SE). BERGGREN, Bertil [SE/SE]; Rönnbergagatan 2 B, S-723 46 Västerås (SE). NYGREN, Jan-Anders [SE/SE]; Karlfeldtsgratan 27 B, S-722 22 Västerås (SE).			
(74) Agent: HOPFGARTEN, Nils; L.A. Groth & Co. KB, P.O. Box 6107, S-102 32 Stockholm (SE).			
		Published With international search report. In English translation (filed in Swedish).	

(54) Title: ROTATING ELECTRIC MACHINE



(57) Abstract

A rotating electric machine of a type with rotating field circuit, intended for direct connection to a distribution or transmission network. At least one electric winding of the machine comprises at least one electric conductor, a first layer with semiconducting properties surrounding the conductor, a solid insulating layer surrounding the first layer, and a second layer with semiconducting properties surrounding the insulating layer. A detecting circuit (16) is also arranged to detect earth faults in the rotating field circuit. Methods of monitoring the resistance of the field winding to earth and of determining the rotor temperature in such a machine is also described.

**FOR THE PURPOSES OF INFORMATION ONLY**

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

AL	Albania	ES	Spain	LS	Lesotho	SI	Slovenia
AM	Armenia	FI	Finland	LT	Lithuania	SK	Slovakia
AT	Austria	FR	France	LU	Luxembourg	SN	Senegal
AU	Australia	GA	Gabon	LV	Latvia	SZ	Swaziland
AZ	Azerbaijan	GB	United Kingdom	MC	Monaco	TD	Chad
BA	Bosnia and Herzegovina	GE	Georgia	MD	Republic of Moldova	TG	Togo
BB	Barbados	GH	Ghana	MG	Madagascar	TJ	Tajikistan
BE	Belgium	GN	Guinea	MK	The former Yugoslav Republic of Macedonia	TM	Turkmenistan
BF	Burkina Faso	GR	Greece	ML	Mali	TR	Turkey
BG	Bulgaria	HU	Hungary	MN	Mongolia	TT	Trinidad and Tobago
BJ	Benin	IE	Ireland	MR	Mauritania	UA	Ukraine
BR	Brazil	IL	Israel	MW	Malawi	UG	Uganda
BY	Belarus	IS	Iceland	MX	Mexico	US	United States of America
CA	Canada	IT	Italy	NE	Niger	UZ	Uzbekistan
CF	Central African Republic	JP	Japan	NL	Netherlands	VN	Viet Nam
CG	Congo	KE	Kenya	NO	Norway	YU	Yugoslavia
CH	Switzerland	KG	Kyrgyzstan	NZ	New Zealand	ZW	Zimbabwe
CI	Côte d'Ivoire	KP	Democratic People's Republic of Korea	PL	Poland		
CM	Cameroon	KR	Republic of Korea	PT	Portugal		
CN	China	KZ	Kazakhstan	RO	Romania		
CU	Cuba	LC	Saint Lucia	RU	Russian Federation		
CZ	Czech Republic	LI	Liechtenstein	SD	Sudan		
DE	Germany	LK	Sri Lanka	SE	Sweden		
DK	Denmark	LR	Liberia	SG	Singapore		
EE	Estonia						

## ROTATING ELECTRIC MACHINE

### Technical field

5 The present invention relates to a rotating electric machine of a type with rotating field circuit, which machine is intended for direct connection to a distribution or transmission network. The invention also relates to the method of monitoring the resistance of the field winding to earth and of determining the rotor temperature.

### 10 Background art

The rotating electric machine according to the present invention may be e.g. a synchronous machine, dual-fed machine, asynchronous static current converter cascade, external pole machine or synchronous flow machine.

15 In order to connect machines of this type to distribution or transmission networks, in the followed called power networks, transformers have previously been used to step up the voltage to the level of the network, i.e. to the range of 130-400 kV.

Generators having a rated voltage of up to 36 kV are described by Paul R. Siedler in an article entitled "36 kV Generators Arise from Insulation Research",  
20 Electrical World, 15 October 1932, pages 524-527. These generators comprise windings of high-voltage cable in which the insulation is divided into various layers having different dielectric constants. The insulating material used consists of various combinations of the three components mica-foil-mica, varnish and paper.

It has now been discovered that by manufacturing windings for the  
25 machine mentioned in the introduction out of an insulated high-voltage electric conductor with solid insulation of a type similar to cables for power transmission, the voltage of the machine can be increased to such levels that the machine can be connected directly to any power network without an intermediate transformer. A typical operating range for these machines is 30 to 800 kV.

30 Furthermore, in system solutions based on brushless exciters for excitation of a synchronous machine, for instance, the rotor winding of the synchronous machine is normally not monitored for earth faults.

The object of the present invention is to provide such a rotating electric machine for direct connection to power networks, with the ability to detect earth faults in the rotating field circuit.

5 Summary of the invention

This object is achieved with a rotating electric machine of the type described in the introductory portion with the characterizing features defined in claim 1.

10 The insulating conductor or high-voltage cable used in the present invention is flexible and is of the type described in more detail in WO 97/45919 and WO 97/45847. The insulated conductor or cable is described further in WO 97/45918, WO 97/45930 and WO 97/45931.

15 Thus, in the device in accordance with the invention the windings are preferably of a type corresponding to cables having solid, extruded insulation, like those currently used for power distribution, such as XPLE-cables or cables with EPR-insulation. Such a cable comprises an inner conductor composed of one or more strands, an inner semiconducting layer surrounding the conductor, a solid insulating layer surrounding this inner semiconducting layer and an outer semiconducting layer surrounding the insulating layer. Such cables are flexible,  
20 which is an important property in this context since the technology for the machine according to the invention is based primarily on winding systems in which the winding is formed from conductors which are bent during assembly. The flexibility of a XPLE-cable normally corresponds to a radius of curvature of approximately 20 cm for a cable 30 mm in diameter, and a radius of curvature of approximately  
25 65 cm for a cable 80 mm in diameter. In the present application the term "flexible" is used to indicate that the winding is flexible down to a radius of curvature in the order of four times the cable diameter, preferably eight to twelve times the cable diameter.

30 The winding should be constructed to retain its properties even when it is bent and when it is subjected to thermal or mechanical stress during operation. It is vital that the layers retain their adhesion to each other in this context. The material properties of the layers are decisive here, particularly their elasticity and

relative coefficients of thermal expansion. In a XPLE-cable, for instance, the insulating layer consists of cross-linked, low-density polyethylene, and the semiconducting layers consist of polyethylene with soot and metal particles mixed in. Changes in volume as a result of temperature fluctuations are completely absorbed as changes in radius of the cable and, thanks to the comparatively slight difference between the coefficients of thermal expansion in the layers in relation to the elasticity of these materials, the radial expansion can take place without the adhesion between the layers being lost.

The material combinations stated above should be considered only as examples. Other combinations fulfilling the conditions specified and also the condition of being semiconducting, i.e. having resistivity within the range of  $10^{-1}$ - $10^6$  ohm-cm, e.g. 1-500 ohm-cm, or 10-200 ohm-cm, naturally also fall within the scope of the invention.

The insulating layer may consist, for example, of a solid thermoplastic material such as low-density polyethylene (LDPE), high-density polyethylene (HDPE), polypropylene (PP), polybutylene (PB), polymethyl pentane (PMP), cross-linked materials such as cross-linked polyethylene (XLPE or PEX), or rubber such as ethylene propylene rubber (EPR) or silicon rubber.

The inner and outer semiconducting layers may be of the same basic material but with particles of conducting material such as soot or metal powder mixed in.

The mechanical properties of these materials, particularly their coefficients of thermal expansion, are affected relatively little by whether soot or metal powder is mixed in or not - at least in the proportions required to achieve the conductivity necessary according to the invention. The insulating layer and the semiconducting layers thus have substantially the same coefficients of thermal expansion.

Ethylene-vinyl-acetate copolymer/nitrile rubber, butylmp polyethylene, ethylene-acrylate-copolymers and ethylene-ethyl-acrylate copolymers may also constitute suitable polymers for the semiconducting layers.

Even when different types of material are used as base in the various layers, it is desirable for their coefficients of thermal expansion to be of the same

order of magnitude. This is the case with the combination of the materials listed above.

The materials listed above have relatively good elasticity, with an E-modulus of  $E < 500$  MPa, preferably  $< 200$  MPa. The elasticity is sufficient for any minor differences between the coefficients of thermal expansion for the materials in the layers to be absorbed in the radial direction of the elasticity so that no cracks or other damages appear and so that the layers are not released from each other. The material in the layers is elastic, and the adhesion between the layers is at least of the same magnitude as in the weakest of the materials.

The conductivity of the two semiconducting layers is sufficient to substantially equalize the potential along each layer. The conductivity of the outer semiconducting layer is sufficiently large to contain the electrical field in the cable, but at the same time sufficiently small not to give rise to significant losses due to currents induced in the longitudinal direction of the layer.

Thus, each of the two semiconducting layers essentially constitutes one equipotential surface, and the winding with these layers will substantially enclose the electrical field within it.

There is, of course, nothing to prevent one or more additional semiconducting layers being arranged in the insulating layer.

According to advantageous embodiments of the machine in accordance with the invention an excitation system for supplying the field circuit comprises a part rotating with the field circuit, and parts of the detecting circuit for earth faults are arranged in said rotating part. The detecting circuit comprises a rotating injection circuit for application on a measuring circuit that is closed through the impedance between field winding and earth, an injection voltage and a measuring unit for measuring the error current resulting in said measuring circuit from the injection voltage, rectifier units being arranged to form rectified absolute values of the injection voltage and the error current, a wireless communication unit also being provided to transmit said absolute values to a stationary calculating unit for monitoring the resistance of the field winding to earth. This means that only two process signals, namely the rectified absolute values for the injection voltage and the error current, need be transmitted to the stationary part to determine the

resistance value to earth. This results in a limited signal interface between the stationary and the rotating part, with less demand on the slip ring-free transmission. The number of rotating units for injection and measuring is also limited. The calculating unit suitably comprises a computer equipment for implementing requisite calculation algorithms.

According to another advantageous embodiment of the machine in accordance with the invention, in which the excitation system is supplied from an exciter with rotating stator side, the injection circuit is supplied from the rotating stator side of the exciter. Voltage fluctuations can then be compensated for by means of software functions in the computer equipment. These functions are based on known circumstances relating to phase shifting in RC circuits and calculation of both real and imaginary current components and absolute values for limit value determination.

According to yet another advantageous embodiment of the machine in accordance with the invention filter circuits are arranged in said measuring circuit in order to filter away harmonics and to block direct voltages. The filter time constants for filtering harmonics shall in that case correspond to the period time of the injection voltage in order to enable the harmonics to be effectively filtered off.

According to yet another advantageous embodiment of the machine in accordance with the invention scaling units are arranged prior to a comparator for comparison of said absolute values of the error current with predetermined limit values, which scaling units are arranged to normalise and compensate the measured error current for variations in the injection voltage before the error current is supplied to the comparator. This is of significance since the injection voltage is altered with the excitation.

According to another advantageous embodiment of the machine in accordance with the invention the above-mentioned problem is solved by the injection circuit being supplied from a constant voltage source.

According to yet another advantageous embodiment of the machine in accordance with the invention a stationary voltage source is arranged to supply the injection circuit via a ring transformer. This enables earth faults to be detected even when the rotor is stationary.

**Brief description of the drawings**

To further explain the invention, embodiments of the invention selected by way of example will be described in more detail with reference to the accompanying drawings in which

- 5 Figure 1 shows a cross section through the insulated conductor used for windings in the machine according to the invention,
- Figure 2 shows a diagram of the excitation system with circuit for detecting earth faults in the field circuit and with means for determining the rotor temperature in an embodiment of the rotating electric machine
- 10 according to the invention,
- Figures 3-6 show equivalent circuits for the measuring circuit included in the detecting circuit for earth faults, in different error cases, and
- Figure 7 illustrates an embodiment of a scaling unit for normalising and compensating the measured signal.

15

**Description of preferred embodiments of the invention**

- Figure 1 shows a cross section through an insulated conductor 11 intended for use in at least one of the windings of the machine in accordance with the invention. The insulated conductor 11 thus comprises a number of strands 35
- 20 made of copper (Cu), for instance, and having circular cross section. These strands 35 are arranged in the middle of the insulated conductor 11. Around the strands 35 is a first semiconducting layer 13. Around the first semiconducting layer 13 is an insulating layer 37, e.g. XPLE insulation. Around the insulating layer 37 is a second semiconducting layer 15. The insulated conductor is flexible and
- 25 this property is retained throughout its service life. Said three layers 13, 37, 15 are such that they adhere to each other even when the insulated conductor is bent. The insulated conductor has a diameter within the interval 20-250 mm and a conducting area within the interval 80-3000 mm<sup>2</sup>.

- Figure 2 shows a circuit diagram of the excitation system in a rotating
- 30 electric machine with one or more windings of the insulated conductor shown in Figure 1 to enable direct connection to a power network. The excitation system



comprises both a rotating injection and supply circuit 16 and a stationary unit 20 for detecting earth faults and for calculating the rotor temperature.

The excitation system thus comprises a rotating part 1 equipped with a rotating exciter G3 which, from the rotating stator side, supplies a diode or thyristor bridge 12 which is connected by its direct current side to the field winding 14 of the machine. An injection and measuring circuit 16 is also provided for use when detecting earth faults in the field circuit, and measuring means 18 to determine the field voltage for temperature calculations. The rotating part 1 also includes a supply means 5 to supply the electronic equipment of the rotating part, and also with a communication unit 3. A measuring means 25 is also provided for measuring the field current  $I_f$ . Wireless communication between the rotating part 1 and the stationary equipment 20 is achieved with the aid of the communication unit 3 and a stationary communication unit 4.

By means of an injection circuit comprising a transformer 8 for voltage adjustment and galvanic separation, the measuring circuit is supplied with a suitable voltage  $U$  via an injection transformer 9, said voltage thus being withdrawn from the AC side of the exciter G3. The measuring circuit includes two parallel RC branches and is closed through the impedance of the field winding 14 to earth. The RC branches serve as current limitation and DC insulation.

The current  $I$  generated in the measuring circuit by the injection voltage  $U$  is sensed by a sensing circuit 22 via a measuring transformer 11 and converted to a corresponding voltage signal which is filtered in the filter circuit 24 and rectified in the rectifier 26. The voltage signal  $U_i$  obtained on the output of the rectifier 26, thus represents the amplitude value for the fundamental tone of the current  $I$  in the measuring circuit.

The injection voltage  $U$  is also filtered and rectified in similar manner in the filter circuit 28 and the rectifier 30, a voltage signal  $U_U$  being obtained on the output of the rectifier, which represents the amplitude value for the fundamental tone of the injection voltage  $U$ .

The filter time constants  $T$  for the filters 24, 28 shall correspond to the period time of the injection voltage  $U$  and measured current  $I$  to effectively filter off all harmonics.

The voltage signals  $U_U$ ,  $U_I$  are transmitted by the communication units 3, 4 to the stationary part 20 for calculation of the resistance of the field winding 14 to earth from these signals in the calculating unit 17.

The calculating unit 17 thus enables earth faults in the field winding 14 to be monitored, and an alarm is tripped when the resistance of the field winding 14 to earth falls below a predetermined level.

$R_j$  denotes the resistance of the field winding 14 to earth, i.e. in practice the resistance to the iron mass of the rotating part, and  $C_j$  denotes the capacitance of the winding 14 to earth. The resistance  $R_j$  may in principle vary from infinitely large to zero.

Figure 3 illustrates an equivalent circuit for the measuring circuit if  $R_j = 0$ , i.e. the "worst" case with the field winding 14 short-circuited to earth. The resultant current  $I_1$  in the circuit can be calculated using known values for the resistance  $R$ , capacitance  $C$  and injection voltage  $U$ , and suitable normalising constants can be determined in accordance with principles described in conjunction with Figure 7 below. The absolute value of the current  $I_1$  corresponds to the value of the measured signal  $U_1$  that is transmitted to the calculating unit 17, as described above in conjunction with Figure 2.

The diagram to the right of the equivalent circuit in Figure 3 illustrates magnitudes and phase positions of the injection voltage  $U$ , composed of a resistive component  $U_r$  and a capacitive component  $U_c$ , and the current  $I_1$ .

Figure 4 shows a corresponding equivalent circuit in fault-free state, i.e. the contact resistance to earth is  $R_j = \infty$ . The capacitance  $C_j$  of the winding 14 to earth can be determined using known values for the injection voltage  $U$ , resistance  $R$  and capacitance  $C$  and measuring the current  $I_2$ .

As in Figure 3, the diagram to the right of the circuit shows magnitudes and phase positions of the injection voltage  $U$ , composed of a resistive component  $U_r$  in phase with the current  $I_2$ , and a capacitive component consisting of the voltage drop  $U_c$  over the capacitors  $C$  and the voltage drop  $U_j$  over the capacitance  $C_j$ , and the current  $I_2$ .

Figure 5 shows a corresponding equivalent circuit in the event of a contact resistance between winding 14 and earth  $R_j$ , where  $0 < R_j < \infty$ , i.e. a state between the states illustrated in Figures 3 and 4. Different limit values for the current  $I_3$  for alarm and tripping can, as mentioned in conjunction with Figure 2, be calculated using known values for the resistances  $R$ , capacitances  $C$ , earthing capacitance  $C_j$ , injection voltage  $U$ , and the currents  $I_1$  and  $I_2$  from the cases shown in Figures 3 and 4, as well as predetermined limit values for the contact resistance to earth  $R_j$ .

The impedance  $Z_1$  across the two parallel branches, each containing  $2R$  in series with  $2C$ , is thus

$$Z_1 = R - j \frac{1}{\omega C}$$

and the transition impedance between the winding 14 and earth  $Z_2$

$$Z_2 = \frac{R_j}{1 + j\omega R_j C_j}$$

the current  $I_3$  being obtained from

$$I_3 = U / (Z_1 + Z_2)$$

The diagram to the right of the circuit in Figure 5 illustrates magnitudes and phase positions of voltages and currents in a corresponding manner as in Figures 3 and 4. From this diagram, it is clear that the current  $I_3$  is in phase with the current  $I_2$  in Figure 4 and includes a current component  $I_{Cj}$  through the transition capacitance  $C_j$  and a current component  $I_{Rj}$  through the contact resistance  $R_j$ , the latter two current components being at right angles to each other in the diagram, i.e. phase-shifted  $90^\circ$ .

Figures 3 and 5 shows cases with errors on the DC side of the supply to the field winding from the exciter G3, see Figure 2. Figure 6 illustrates a situation with faults on the AC side of the rectifier bridge 12. A fault on the AC side is characterized by the addition of an extra supply source  $U_{ac}$ , and by the absolute

value of the current being composed of two components - one driven by the ordinary injection voltage  $U$  and one driven by the potential level of the fault point to earth, represented by the voltage  $U_{ac}$ . In the event of faults on the AC side, therefore, the total absolute value of the error current will exceed the limit values  
5 calculated in the case illustrated in Figure 5 - often by a good margin - resulting in the alarm being tripped.

The corresponding phase diagram to the right in Figure 6 corresponds to that in Figure 5.

In the event of variations in the injection voltage  $U$  the measured signals  
10 must be compensated by scaling. Alternatively, the predetermined limit values for alarm tripping or releasing, etc. in a comparator must be changed, which is considerably more complicated.

Figure 7 shows a scaling unit 32, 34 included in the calculating unit 17 in Figure 2. In this scaling unit 32, 34 the measured value  $U_I$ , representing the  
15 absolute value of the current  $I$ , is normalised by multiplying it by a normalising constant  $K1$ . A suitable magnitude for the normalising constant  $K1$  can be determined by means of a measuring procedure in accordance with Figure 3. Similarly, the measured signal  $U_U$  for variations in the injection voltage  $U$  is compensated by scaling with a compensation constant  $K2$ , wherein  $K2=U_U$  at the  
20 time of normalising the measured signal  $U_I$ . The current  $I_n$ , normalised and compensated with regard to variations in the injection voltage  $U$ , is supplied to a comparator 38 in which this current  $I_n$  is compared with various predetermined limit values  $Lim\ 1$ ,  $Lim\ 2$ ,  $Lim\ 3$  for tripping the alarm, emitting a tripping signal, etc.

25 The measuring means 18 measure the field voltage and the measuring means 25 measures the field current, and corresponding measured signals  $U_F$  and  $I_F$  are transmitted via the wireless communication units 3, 4 to a unit 40 in the stationary equipment 20 for calculating the rotor temperature from these measured signals, see Figure 2. In the filter 42 in the measuring means 18 the  
30 field voltage signal is filtered with a time constant  $T1$  which shall correspond to 0.3 times the no-load time constant of the field winding 14. When the electric machine

is not synchronized on the network, it has a time constant corresponding to the no-load time constant, whereas if the machine is connected to the network this time constant is altered by a factor of approximately 0.3, depending on the inductance of the network.

- 5           The unit 40 may in turn be connected to indicating means for the rotor temperature or alarm, for instance, or tripping means to activate these depending on the determined value for the rotor temperature.

- Numerous modifications and variations of the embodiments described above are of course possible within the scope of the invention. The invention is  
10       thus also applicable to stationary solutions such as static exciters, and the supply voltage to the injection unit can be transformed to the rotating part by means of a ring transformer so that earth faults can also be detected when the machine is stationary.
-

## CLAIMS

1. A rotating electric machine of a type with rotating field circuit, which machine is intended for direct connection to a distribution or transmission network,  
5 **characterized** in that at least one electric winding of the machine comprises at least one electric conductor, a first layer with semiconducting properties surrounding the conductor, a solid insulating layer surrounding the first layer, and a second layer with semiconducting properties surrounding the insulating layer, and in that a detecting circuit is provided for detecting earth faults in the rotating  
10 field circuit.
2. A machine as claimed in claim 1, **characterized** in that the potential of the first layer is substantially similar to the potential of the conductor.
- 15 3. A machine as claimed in claim 1 or claim 2, **characterized** in that the second layer is arranged to form a substantially equipotential surface surrounding the conductor.
4. A machine as claimed in claim 3, **characterized** in that the second layer  
20 is connected to a predetermined potential.
5. A machine as claimed in claim 4, **characterized** in that said predetermined potential is earth potential.
- 25 6. A machine as claimed in any of the preceding claims, **characterized** in that at least two adjacent layers of the machine winding have substantially the same coefficients of thermal expansion.
7. A machine as claimed in any of the preceding claims, **characterized** in  
30 that the conductor comprises a number of strands, at least some of which are in electrical contact with each other.

8. A machine as claimed in any of the preceding claims, **characterized** in that each of said three layers is firmly joined to adjacent layers along substantially its whole contact surface.

5 9. A machine as claimed in any of the preceding claims, **characterized** in that said layers are arranged to adhere to each other even when the insulated conductor is bent.

10 10. A rotating electric machine of a type with rotating field circuit, which machine is intended for direct connection to a distribution or transmission network, **characterized** in that at least one winding of the machine is formed of a cable comprising one or more current carrying conductors, each conductor having a number of strands, an inner semiconducting layer arranged around each conductor, an insulating layer of solid insulating material arranged around said  
15 inner semiconducting layer, and an outer semiconducting layer arranged around the insulating layer, and in that a detecting circuit is arranged to detect earth faults in the rotating field circuit.

20 11. A machine as claimed in claim 10, **characterized** in that said cable comprises a sheath.

12. A machine as claimed in any of the preceding claims, **characterized** in that an excitation system for supplying the field circuit comprises a part rotating with the field circuit, and in that an injection and measuring unit for said detecting  
25 circuit is arranged in said rotating part.

13. A machine as claimed in any of the preceding claims, **characterized** in that the detecting circuit comprises an injection circuit for application on a measuring circuit that is closed through the impedance between field winding and  
30 earth, an injection voltage and a measuring unit for measuring the error current resulting in said measuring circuit from the injection voltage, and in that rectifier units are arranged to form rectified absolute values of the injection voltage and th

error current, a wireless communication unit also being provided to transmit said absolute values to a stationary calculating unit for monitoring the resistance of the field winding to earth.

5 14. A machine as claimed in claim 13, wherein the excitation system is supplied from an exciter with rotating stator side, **characterized** in that the injection circuit is supplied from the rotating stator side of the exciter.

10 15. A machine as claimed in claim 13 or claim 14, **characterized** in that filter circuits are arranged in said measuring circuit in order to filter away harmonics and to block direct voltages.

15 16. A machine as claimed in any of claims 13-15, **characterized** in that a comparator is arranged to compare said absolute values of the error current with predetermined limit values and, depending on the result of the comparison, to trip alarms.

20 17. A machine as claimed in claim 16, **characterized** in that scaling units are arranged prior to the comparator in order to normalise and compensate the measured error current for variations in the injection voltage before the error current is supplied to the comparator.

25 18. A machine as claimed in any of the preceding claims, **characterized** in that measuring means are arranged to measure the voltage and current of the field winding and transmit these values to a unit for calculating the rotor temperature.

30 19. A machine as claimed in claim 18, **characterized** in that the unit for calculating the rotor temperature is stationary and in that said measured voltage and current values for the field winding can be transmitted to said calculating unit via the wireless communication unit.



20. A machine as claimed in claim 18 or claim 19, **characterized** in that an alarm is connected to the calculating unit which alarm is tripped when the temperature exceeds a predetermined limit value.
- 5 21. A machine as claimed in claim 13, **characterized** in that a stationary voltage source is arranged to supply the injection circuit via a ring transformer.
22. A machine as claimed in claim 13, **characterized** in that the injection circuit is supplied from a constant voltage source.
- 10 23. A method for a rotating electric machine of a type with rotating field circuit, which machine is intended for direct connection to a distribution or transmission network, wherein at least one electric winding of the machine comprises at least one electric conductor, a first layer with semiconducting properties surrounding the conductor, a solid insulating layer surrounding the first layer, and a second layer with semiconducting properties surrounding the insulating layer, **characterized** in that an injection voltage is supplied to a measuring circuit that is closed through the impedance between field winding and earth, and the resulting error current in the measuring circuit is measured, whereupon rectified absolute values of the injection voltage and the error current are formed and transmitted to a calculating unit for monitoring the resistance of the field winding to earth.
- 15 24. A method as claimed in claim 23, **characterized** in that harmonics in the measuring circuit are filtered away.
- 25 25. A method as claimed in 23 or claim 24, **characterized** in that said absolute values of the error current are compared with predetermined limit values and an alarm is tripped depending on the result of the comparison.
- 30 26. A method as claimed in claim 25, **characterized** in that prior to the comparison, the error current measured is normalised and compensated for variations in the injecting voltage.

27. A method for a rotating electric machine of a type with rotating field circuit, which machine is intended for direct connection to a distribution or transmission network, wherein at least one electric winding of the machine comprises at least one electric conductor, a first layer with semiconducting properties surrounding the conductor, a solid insulating layer surrounding the first layer, and a second layer with semiconducting properties surrounding the insulating layer, characterized in that the voltage and current of the field winding are measured and the rotor temperature is calculated from these measured values.

Fig. 1

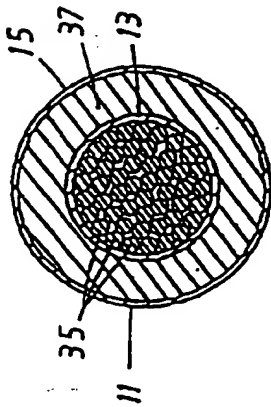
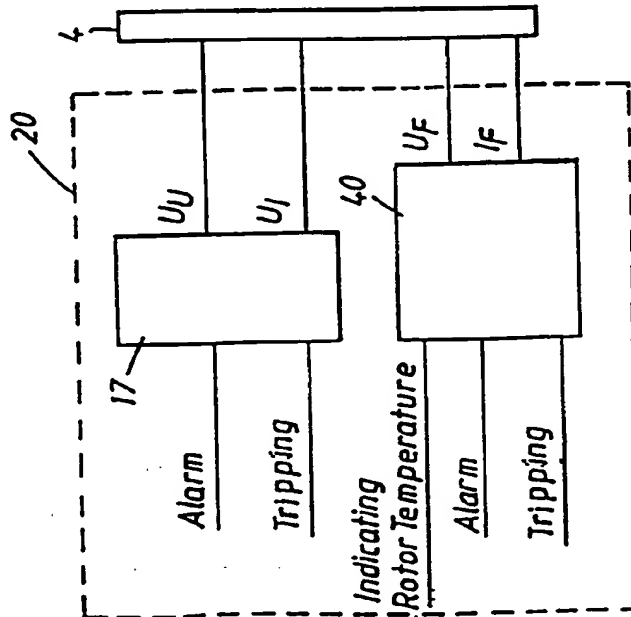
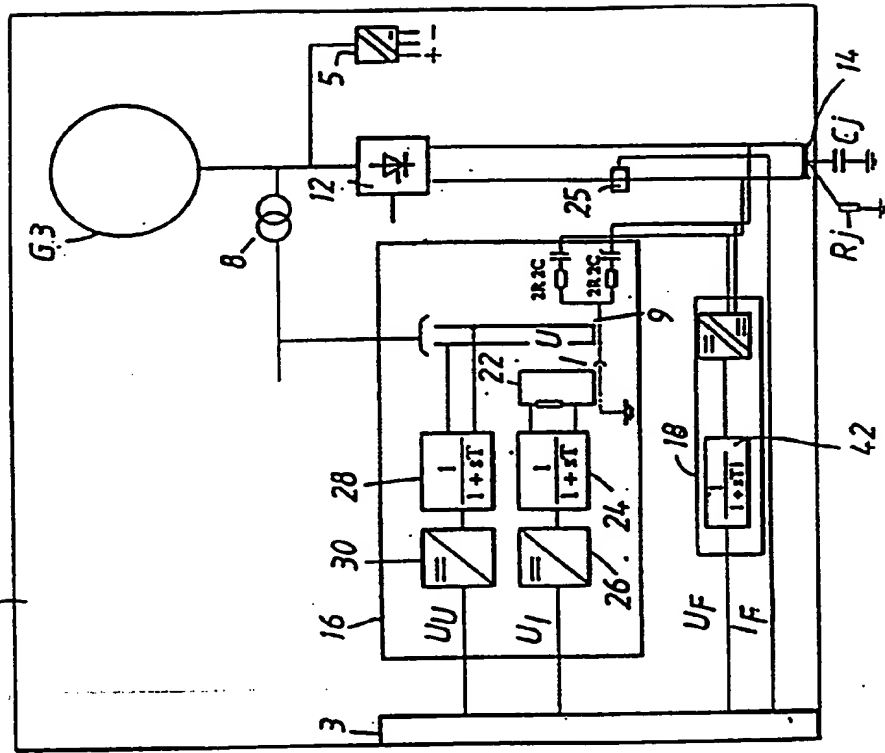


Fig. 2



**THIS PAGE BLANK (USPTO)**

2 / 3

Fig. 3

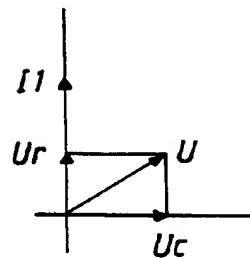
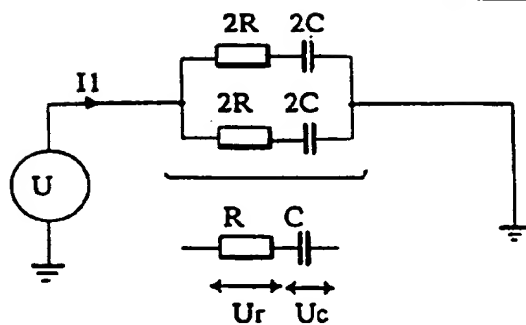


Fig. 4

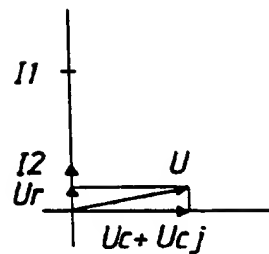
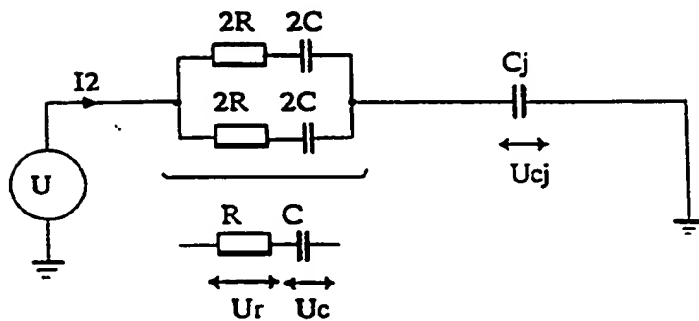
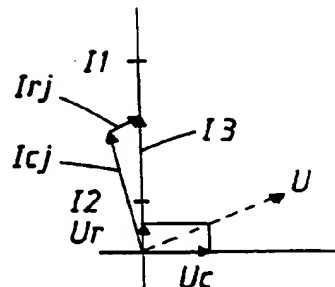
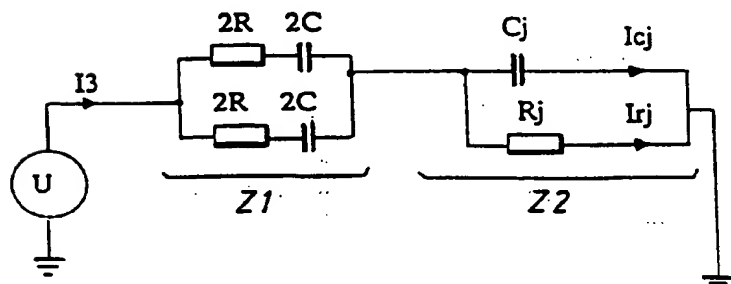


Fig. 5



**THIS PAGE BLANK (USPTO)**

3 / 3

Fig. 6

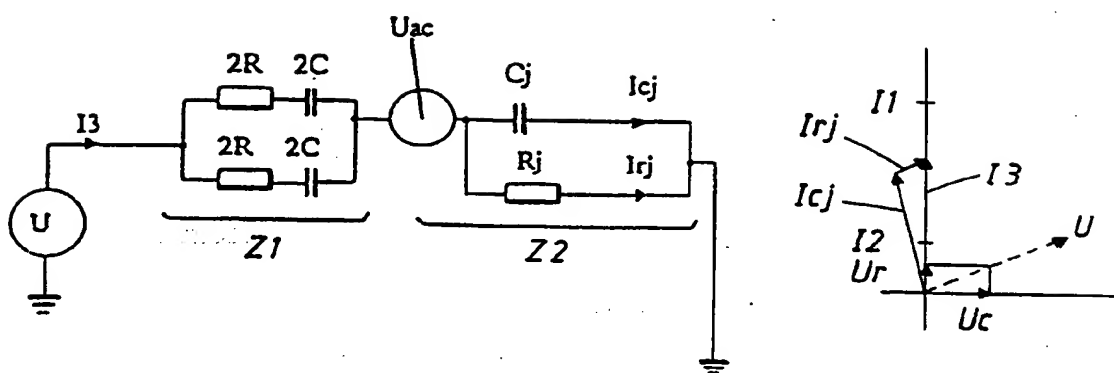
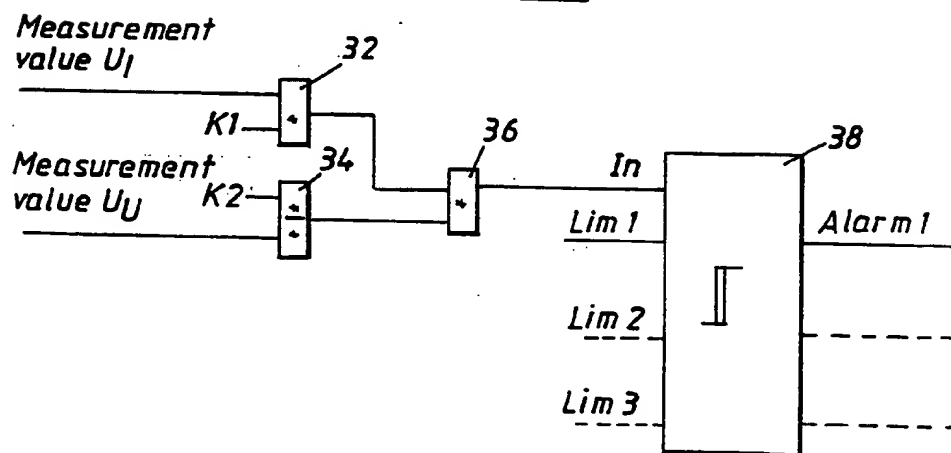


Fig. 7



**THIS PAGE BLANK (USPTO)**



## INTERNATIONAL SEARCH REPORT

International application No.

PCT/SE 98/01740

## A. CLASSIFICATION OF SUBJECT MATTER

IPC6: H02K 3/40, G01R 31/06

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC6: H02K

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

SE,DK,FI,NO classes as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

WPI

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 4785138 A1 (O. BREITENBACK ET AL.), 15 November 1988 (15.11.88), see the whole document --	1-27
Y	US 3684821 A1 (H. MIYAUCHI ET AL.), 15 August 1972 (15.08.72), column 2, line 44 - line 64 --	1-27
Y	EP 0642027 A1 (ABB MANAGEMENT AG), 8 March 1995 (08.03.95), page 1, line 40 - page 2, line 11 --	1-26
Y	EP 0274691 A1 (HITACHI, LTD.), 20 July 1988 (20.07.88), column 2, line 50 - column 3, line 41 --	1-27



Further documents are listed in the continuation of Box C.



See patent family annex.

## \* Special categories of cited documents:

- "A" document defining the general state of the art which is not considered to be of particular relevance
- "E" earlier document but published on or after the international filing date
- "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
- "O" document referring to an oral disclosure, use, exhibition or other means
- "P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance: the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance: the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

3 December 1998

Date of mailing of the international search report

11-12-1998

Name and mailing address of the ISA/  
Swedish Patent Office  
Box 5055, S-102 42 STOCKHOLM  
Facsimile No. +46 8 666 02 86

Authorized officer

Håkan Sandh  
Telephone No. +46 8 782 25 00



**INTERNATIONAL SEARCH REPORT**  
Information on patent family members

International application No.  
**PCT/SE 98/01740**

Patent document cited in search report			Publication date	Patent family member(s)	Publication date
US	4785138	A1	15/11/88	DE 3543106 A,C	11/06/87
US	3684821	A1	15/08/72	NONE	
EP	0642027	A1	08/03/95	DE 4329382 A JP 7083987 A US 5508620 A	02/03/95 31/03/95 16/04/96
EP	0274691	A1	20/07/88	CA 1269704 A DE 3779286 A JP 1954531 C JP 6087642 B JP 63154040 A US 4851766 A	29/05/90 25/06/92 28/07/95 02/11/94 27/06/88 25/07/89
EP	0671632	A2	13/09/95	CA 2143364 A CN 1112682 A JP 7241027 A US 5675465 A US 5764462 A	26/08/95 29/11/95 12/09/95 07/10/97 09/06/98
US	4914386	A1	03/04/90	CA 1323398 A	19/10/93
US	3593123	A1	13/07/71	GB 1226451 A	31/03/71
US	5036165	A1	30/07/91	US 5066881 A US 5067046 A CA 1245270 A US 4853565 A	19/11/91 19/11/91 22/11/88 01/08/89
US	4510077	A	09/04/85	CH 664646 A,B DE 3439093 A,C FR 2554456 A,B GB 2148880 A,B JP 1789646 C JP 4078576 B JP 60131853 A	15/03/88 15/05/85 10/05/85 05/06/85 29/09/93 11/12/92 13/07/85

**THIS PAGE BLANK (USPTO)**